Horticultural performance of 'Fuji Suprema' and 'Maxi Gala' apple trees trained at Tall Spindle and Bi-Axis systems grafted on different rootstocks in Southern Brazil

Leo Rufato[1] **Juliana Fátima Welter Woitexen**[2] **Alberto Ramos Luz**[1*]
Pricila Santos da Silva[3] **Tiago Afonso de Macedo**[4] **Marilia Feliciano Goulart Pereira**[1]
Augusto Schütz Ferreira[5] **Aike Anneliese Kretzschmar**[1]

[1]Programa de Pós-graduação em Produção Vegetal, Universidade do Estado de Santa Catarina (UDESC), 88520-000, Lages, SC, Brasil. E-mail: albertoramosluz@yahoo.com.br. *Corresponding author.
[2]Centro de Educação Profissional Vidal Ramos, Canoinhas, SC, Brasil.
[3]Centro de Educação Profissional Caetano Costa, São José do Cerrito, SC, Brasil.
[4]Agromillora Produção e Comercio de Mudas Vegetais, Brotas, SP, Brasil.
[5]Pró Planta Soluções Agronômicas, Bom Retiro, SC, Brasil.

ABSTRACT: *The use of new rootstocks combined with different training systems have been studied to increase productivity, fruit quality, and reduce costs. Another important factor is the validation of studies under replanting conditions, due to the growing limitation of new areas for planting commercial apple orchards in Brazil. The present study aimed to evaluate the behavior of 'Fuji Suprema' and 'Maxi Gala' apple trees in two training systems grafted on two rootstocks. The study occurred during the seasons 2016/17, 2017/18 and 2018/19, in an orchard located in southern Brazil in an area previously cultivated with apple trees. A randomized block design consisting of a 2x2 factorial was used, with Tall Spindle and Bi-Axis as the training system and 'M.9' and 'G.213' as rootstocks of Fuji Suprema and Maxi Gala cultivars. Variables were evaluated to determine tree vigor, as well as yield and fruit quality characteristics. It was observed that 'G.213' promoted higher vigor for both cultivars as well as the Bi-Axis training system in the Maxi Gala cultivar. The highest yield was observed in Tall Spindle as well as the rootstock 'G.213' in both cultivars. The most significant changes on fruit quality occurred in the Bi-Axis training system, presenting higher intensity of red color as well as 'Maxi Gala' grafted on 'G.213' rootstock.*
Key words: *Malus domestica, Geneva®, yield efficiency, fruit quality.*

Comportamento agronômico de macieiras 'Fuji Suprema' e 'Maxi Gala' conduzidas em Tall Spindle e Bi-Axis enxertadas em diferentes porta-enxertos no Sul do Brasil

RESUMO: *A utilização de novos porta-enxertos e diferentes sistemas de condução tem sido estudado para aumentar a produtividade, qualidade dos frutos e reduzir custos. Outro fator importante é a validação de estudos em condições de replantio, devido à crescente limitação de novas áreas para o plantio comercial de pomares de macieiras no Brasil. O presente estudo teve como objetivo avaliar o comportamento de macieiras 'Fuji Suprema' e 'Maxi Gala' em dois sistemas de condução enxertados sobre dois porta-enxertos. O estudo ocorreu durante as safras 2016/17, 2017/18 e 2018/19, em um pomar localizado no sul do Brasil, em área previamente cultivada com macieiras. Utilizou-se delineamento de blocos casualizados, consistindo em um fatorial 2x2, sendo Tall Spindle e Bi-Axis como sistemas de condução e 'M.9' e 'G.213' como porta-enxertos das cultivares Fuji Suprema e Maxi Gala. Foram avaliadas variáveis para determinar o comportamento vegetativo, bem como as características de produtividade e qualidade dos frutos. Observou-se que 'G.213' promoveu maior vigor para ambas cultivares, assim como o sistema de condução Bi-Axis na cultivar Maxi Gala. O maior rendimento foi observado nas macieiras conduzidas em Tall Spindle e enxertadas sobre 'G.213' em ambas cultivares. As mudanças mais significativas na qualidade dos frutos ocorreram nas macieiras conduzidas em Bi-Axis, apresentando maior intensidade de coloração vermelha, assim como na macieira 'Maxi Gala' enxertada sobre 'G.213'.*
Palavras-chave: *Malus domestica, Geneva®, eficiência produtiva, qualidade de frutos.*

INTRODUCTION

The main apple growing regions in the world have undergone major changes over the past few years. These major changes are related to the use of virus-free materials, dwarfing rootstocks, as well as more efficient training systems, enabling high density planting (PETRI et al., 2011), improving light interception and distribution for the purpose of optimizing fruit quality and yield (REIG et al., 2019). In Brazil, apple cultivation is mainly carried out in medium to high planting density systems (1000 to 4000 trees ha^{-1}) (RUFATO et al., 2019). The most used rootstocks in apple-growing regions are combinations of 'Marubakaido' (Maruba) and 'M.9' as interstem (Maruba/M.9) and Maruba in regions of high altitude,

characterized by shallow and stony soils (MACEDO et al., 2019) and 'M.9' in flat areas with deep soils. These rootstocks have several disadvantages, such as low yield efficiency, presence of burr knots, high formation of rootstock suckers and high labor costs when using Maruba, whereas 'M.9' has poor root development, low adaptability to shallow soils and it is sensitive to "replanting diseases", to woolly apple aphid (*Eriosoma lanigerum*) and to crown gall disease (*Agrobacterium tumefaciens*) (REIG et al., 2019; DENARDI et al., 2015).

According to RUFATO et al. (2021), in Brazil there is a gradual change in the use of different rootstocks than the traditional Maruba and M.9, mainly due to the introduction of different genotypes from the Geneva® series. Most of Geneva® rootstocks are resistant simultaneously to cold hardy, replant soils, woolly apple aphids, crown gall disease and viruses, besides having high yield efficiency with early production and high yield. The 'G.213' is a Geneva® genotype classified as dwarf, providing vigor, precocity production and fruit quality similar to 'M.9' (FAZIO et al., 2015; REIG et al., 2018). Although, there are indications of some rootstocks of the CG series for planting in commercial orchards, there is still little information available about these rootstocks in Brazilian conditions.

Allied to the use of more efficient rootstocks, the use of training systems allows a better balance between vegetative growth and fruit production, mainly by increasing the light distribution into the canopy (ROBINSON, 2011; REIG et al., 2019). Central leader and its derivations, like Tall Spindle, are the most commonly training systems used to grow apple trees in Brazil, as well as in the United States. Dwarf rootstocks and training systems with better light interception were decisive factors in increasing planting density and yield efficiency over de last years in Brazil (PETRI et al., 2011). In addition to the many central leader training systems, other systems have been developed around the world, such as Bi-Axis, which is ideal for increasing planting density as it divides the tree vigor into two main axes/leaders (MUSACCHI, 2008). It promotes good fruits exposure to light, simplifies cultural management such as pruning, shoot bending and harvesting (DORIGONI et al., 2011).

In the early 2000s, there were attempts to grown apple trees in different training systems in Brazil, but with no success. Today the scenario is different, Brazilian growers are increasingly interested in learning new cultivation techniques due to the lack of workers and the search for high quality fruits,

considered as the main difficulties in the national apple production. Therefore, this research evaluated the performance of 'Maxi Gala' and 'Fuji Suprema' apple trees grafted on 'M.9' and 'G.213' rootstocks trained at Tall Spindle and Bi-Axis systems with the same number of stems per area in Southern Brazil.

MATERIALS AND METHODS

The study was conducted in a commercial orchard located in Vacaria - RS, Southern Brazil, under geographical coordinates 50º54'12"W and 28º24'93"S, with an elevation of 930 m, during the years 2016-2019. The climate of Vacaria, according to the classification of Köeppen is Cfb type: humid temperate climate with mild summers. The soil of the region is classified as typical dystrophic Bruno Latossolo with deep soils, well drained, with high clay content, marked acidity and low nutrient reserve for plants. The soil has a predominant mineralogy of kaolinite, iron and aluminum oxides and a high content of organic matter (SANTOS et al., 2006).

The orchard was established in July 2014, in a replanting area previously cultivated with apple trees for twenty years followed by one-year rest period with maize cultivation. The trees received all cultural treatments by the company according to the standards of integrated production of apples. It was used one single stem nursery trees, which were cut headed after planting and to make a Bi-Axis tree, two chip-bud grafts were made in each tree to make the two main stems. The orchard was designed according to the cultivar, rootstock, training system, and planting densities. 'Maxi Gala' trained at Tall Spindle was planted at 0.7 m between trees while trained at Bi-Axis 1.4 m between trees, in order to have one axe each 0.7 m, on both rootstocks. 'Fuji Suprema' trained at Tall Spindle was planted at 0.9 m between trees while trained at Bi-Axis 1.8 m between trees, on both rootstocks. The experimental design was a randomized block in a 2x2 factorial design (training systems x rootstocks) in Maxi Gala and Fuji Suprema cultivars, containing six repetitions and ten trees per plot. The evaluations started in the winter of 2016/17 season up to harvest of 2019.

The vegetative growth was evaluated in the dormant period of the trees, measuring the tree height (from the grafting point to the end of the leader), the canopy volume (obtained multiplying the tree width, length, and height from the first lower lateral branch to the end of the leader), number of lateral branches per tree and the trunk cross-sectional area (TCSA) of the scion cultivar (measured 10 cm above the grafting point).

The productive behavior was evaluated individually from each tree, obtaining the fruit production by tree allowing to obtain the estimated yield. The yield efficiency was calculated by the relation between the average production of each tree divided by the trunk cross-sectional area. The fruit weight was obtained by dividing the fruit production by the number of fruits, and a sample of 20 fruits per plot were used to obtain the fruit diameter, the flesh firmness (determined by a digital texture analyzer TA.XT express/TA.XT2icon, with an 11mm tip), the soluble solids content (using a digital refractometer ITREFD-45) and the red color intensity was obtained through a digital colorimeter Konica Minolta CR-400, with the reading performed in the region with the highest red color intensity.

The obtained data were submitted to the Shapiro-Wilk test ($\alpha = 0.05$) to verify the adherence to the normal distribution. The values that did not present normality were transformed into $\sqrt{(x + 0.5)}$, where x is the average obtained of each variable. Subsequently, the means were subjected to analysis of variance and, when differences were observed at the 5% error probability, the Tukey test ($\alpha = 0.05$) was used to separate the means.

RESULTS

Maxi Gala cultivar

The variance analysis of the data showed significant effect of the interaction between training systems and rootstocks (TS x RT) for the variables tree height (2016/17 and 2017/18), trunk cross-sectional area (TCSA) (2016/17 and 2017/18), canopy volume (2017/18), fruit production, estimated yield (2016/17 and 2018/19), yield efficiency (2016/17 and 2018/19), fruit weight (2018/19), red color intensity, and flesh firmness (2017/18 and 2018/19). Given the absence of interaction significance, the other factors were analyzed in their average effect (Tables 1, 2, 3 and 4).

Trees trained in Tall Spindle and grafted on 'M.9' showed higher height for the first two years of evaluation; although, without difference from the trees grafted on 'G.213' in the first season (Table 1). In contrast, Bi-Axis trained trees grafted on 'M.9' had lower height. For the third evaluated season, there were no differences in tree height influenced by the rootstocks, but trees trained in Tall Spindle had higher increment in height. Initially, the trees trained in Tall Spindle and grafted on 'G.213' showed higher canopy volume (Table 1); however, from the second evaluated season, there was a greater increase in the

Table 1 - Vegetative behavior of 'Maxi Gala' and 'Fuji Suprema' apple trees grafted on 'M.9' and 'G.213' rootstocks trained at Tall Spindle and Bi-Axis systems in Southern Brazil.

Season	Training System/Rootstock	Tree height (m)				Canopy Volume (m³)				TSCA (cm²)				Nº of lateral branches (Nº tree⁻¹)			
		M.9		G.213		M.9		G.213		M.9		G.213		M.9		G.213	
Maxi Gala																	
2016/17	Tall Spindle	2.1	a^{ns}	2.0	a	1.5	a*	2.6	a	4.4	a*	6.0	b	6.4	b*	13.3	b
	Bi-axis	1.5	b*	1.8	b	0.5	b*	1.5	b	4.2	a*	6.9	a	9.6	a*	17.9	a
2017/18	Tall Spindle	2.7	a*	2.3	a	1.9	a*	3.0	b	6.5	a*	9.5	b	14.1	b*	18.2	b
	Bi-axis	1.9	b*	2.2	a	2.0	a*	4.3	a	7.5	a*	12.3	a	23.5	a*	28.5	a
2018/19	Tall Spindle	2.9	a^{ns}	2.8	a	3.5	b*	5.0	b	10.3	b*	12.2	b	16.0	b*	18.3	b
	Bi-axis	2.3	b^{ns}	2.4	b	4.4	a*	5.5	a	13.4	a*	16.7	a	22.3	a*	28.6	a
Fuji Suprema																	
2016/17	Tall Spindle	2.0	a^{ns}	2.1	a	1.6	a*	2.8	a	5.2	a*	8.0	a	10.4	b*	14.4	b
	Bi-axis	1.6	b^{ns}	1.5	b	1.0	b*	1.1	b	5.5	a*	6.7	b	12.3	a*	20.2	a
2017/18	Tall Spindle	2.5	a^{ns}	2.5	a	2.4	b*	3.6	a	9.0	b*	12.5	a	15.4	b*	21.4	b
	Bi-axis	2.1	b^{ns}	1.9	b	3.4	a^{ns}	3.3	a	11.0	a^{ns}	11.6	a	28.6	a*	32.2	a
2018/19	Tall Spindle	2.9	a^{ns}	2.7	a	4.5	b^{ns}	3.8	b	17.3	a^{ns}	19.7	a	17.5	b^{ns}	17.9	b
	Bi-axis	2.5	b^{ns}	2.3	b	5.2	a^{ns}	4.6	a	19.5	a^{ns}	18.8	a	25.2	a^{ns}	29.2	a

Note: * represents significant and ^{ns} not significant according to the Tukey's test (P ≤ 0.05) for comparison between rootstocks in the line. Means within a column followed by the same letter are not significantly different according to the Tukey's test (P ≤ 0.05) for comparison between training systems.

Table 2 - Productive behavior of 'Maxi Gala' and 'Fuji Suprema' apple trees grafted on 'M.9' and 'G.213' rootstocks trained at Tall Spindle and Bi-Axis systems in Southern Brazil.

Season	Training System/Rootstock	---Production (Kg tree^{-1})---				Estimated yield --------------(t ha^{-1})-------------				Yield efficiency ----------(Kg cm^2)---------			
		-----M.9----		--G.213--		------M.9-----		---G.213---		-----M.9----		--G.213--	
--Maxi Gala--													
2016/17	Tall Spindle	1.5	a*	5.6	a	5.5	a*	20.0	a	0.4	a*	0.9	a
	Bi-axis	1.8	a*	4.3	b	3.2	b*	7.7	b	0.4	a*	0.6	b
2017/18	Tall Spindle	7.5	a*	13.4	b	26.6	a*	47.8	a	1.1	a*	1.4	a
	Bi-axis	8.3	a*	17.5	a	14.8	b*	31.2	b	1.1	a*	1.4	a
2018/19	Tall Spindle	5.8	a*	9.5	a	20.7	a*	34.1	a	0.5	a*	0.8	a
	Bi-axis	5.7	a^{ns}	6.6	b	10.2	b^{ns}	11.8	b	0.4	a^{ns}	0.4	b
--Fuji Suprema--													
2016/17	Tall Spindle	1.6	a*	7.8	a	4.6	a*	21.6	a	0.3	a*	1.0	a
	Bi-axis	0.3	b*	2.9	b	0.4	b*	4.1	b	0.0	b*	0.4	b
2017/18	Tall Spindle	5.7	a^{ns}	7.3	b	15.8	a*	20.2	a	0.6	a^{ns}	0.6	b
	Bi-axis	5.2	a*	11.0	a	7.30	b*	15.3	b	0.5	a*	0.8	a
2018/19	Tall Spindle	5.0	b*	12.7	a	13.9	a*	35.2	a	0.2	b*	0.6	a
	Bi-axis	10.0	a^{ns}	10.1	a	13.6	a^{ns}	14.1	b	0.5	a^{ns}	0.6	a

Note: * represents significant and ^{ns} not significant according to the Tukey's test (P ≤ 0.05) for comparison between rootstocks in the line. Means within a column followed by the same letter are not significantly different according to the Tukey's test (P ≤ 0.05) for comparison between training systems.

canopy volume of Bi-Axis trees grafted on 'G.213'. Regardless of the canopy/rootstock combination, the Bi-Axis system and the 'G.213' rootstock provided the highest canopy volume. The TCSA was larger in Bi-Axis trained trees grafted on 'G.213' in the first two evaluated seasons (Table 1). For all the years of study, the largest number of lateral branches was observed in trees trained in Bi-Axis as well as grafted in 'G.213' (Table 1).

For two seasons, the highest yields were observed in Tall Spindle trained trees grafted on 'G.213', except for the second season, when there was higher production on Bi-Axis trained trees grafted on 'G.213' (Table 2). In the first and last evaluated season, the highest estimated yield and the highest yield efficiency were obtained from Tall Spindle trained trees grafted on 'G.213' (Table 2). In the 2017/18 season, the Tall Spindle system and the 'G.213' rootstock induced higher yields, but in relation to the yield efficiency no differences were observed between the training systems. In the 2017/18 harvest, the 'G.213' induced greater yield efficiency to apple trees than the 'M.9'.

Fruit weight differed only in the last evaluated season, with higher fruit weight from Tall Spindle trained trees grafted on 'G.213'. There was no influence of training systems on fruit diameter; conversely, the rootstocks influenced the fruit diameter with different behavior among seasons (Table 3). The flesh firmness of the fruits showed variable behavior among seasons (Table 3). Differences were observed on soluble solids content only in the last evaluated season, where fruits obtained from apple trees trained in Bi-Axis and grafted on 'G.213' had higher contents. The reddish fruits were obtained from Bi-Axis trained trees grafted on 'G.213', except for the second evaluated season, where the averages were higher on the fruits from Tall Spindle trained trees grafted on 'G.213' (Table 4).

Fuji Suprema cultivar

The variance analysis of the data showed significant effect of the interaction between training systems and rootstocks (TS x RT) for TCSA (2016/17 and 2017/18), canopy volume (2017/18), fruit production, estimated yield (2016/17 and 2018/19), yield efficiency, red color intensity (2017/18) and flesh firmness (2018/19). Given the absence of interaction significance, the other factors were analyzed in their average effect (Tables 1, 2, 3 and 4).

Table 3 - Post-harvest behavior of 'Maxi Gala' and 'Fuji Suprema' apples from trees grafted on 'M.9' and 'G.213' rootstocks trained at Tall Spindle and Bi-Axis systems in Southern Brazil.

Season	Training System/Rootstock	Fruit weight (g) M.9	G.213	Fruit diameter (mm) M.9	G.213	Flesh firmness (N) M.9	G.213	Soluble solids (°Brix) M.9	G.213
		---Maxi Gala---							
2016/17	Tall Spindle	181 a^{ns}	179 a	73 a^{*}	72 a	71.5 a^{ns}	72.1 a	12.5 a^{ns}	12.5 a
	Bi-axis	179 a^{ns}	179 a	74 a^{*}	72 a	73.3 a^{ns}	72.8 a	12.6 a^{ns}	13.2 a
2017/18	Tall Spindle	129 a^{ns}	125 a	66 a^{ns}	65 a	75.8 a^{ns}	71.1 b	11.5 a^{ns}	12.0 a
	Bi-axis	124 a^{ns}	123 a	65 a^{ns}	65 a	77.4 a^{*}	82.3 a	11.3 a^{ns}	12.1 a
2018/19	Tall Spindle	145 a^{*}	167 a	65 a^{ns}	68 a	85.7 a^{*}	76.4 b	11.5 b^{*}	12.0 b
	Bi-axis	148 a^{*}	159 b	65 a^{ns}	69 a	85.4 a^{ns}	84.7 a	12.0 a^{*}	12.5 a
		---Fuji Suprema---							
2016/17	Tall Spindle	168 a^{*}	184 a	77 a^{ns}	78 a	68.5 a^{ns}	62.8 a	13.1 a^{*}	13.4 a
	Bi-axis	155 b^{*}	172 b	73 b^{ns}	76 b	64.3 a^{ns}	65.5 a	12.7 a^{*}	14.0 a
2017/18	Tall Spindle	134 a^{ns}	141 a	72 a^{ns}	70 a	77.4 a^{ns}	77.0 a	13.6 a^{ns}	14.3 a
	Bi-axis	143 a^{ns}	139 a	69 a^{ns}	70 a	77.8 a^{ns}	74.0 a	13.7 a^{ns}	13.7 a
2018/19	Tall Spindle	156 a^{ns}	153 a	71 a^{ns}	71 a	76.6 a^{*}	69.4 b	13.9 a^{ns}	13.8 a
	Bi-axis	156 a^{ns}	160 a	70 a^{ns}	70 a	72.5 a^{*}	79.7 a	14.0 a^{ns}	14.9 a

Note: * represents significant and ^{ns} not significant according to the Tukey's test ($P \leq 0.05$) for comparison between rootstocks in the line. Means within a column followed by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$) for comparison between training systems.

Tall Spindle trained trees were taller than Bi-Axis trees. Comparing the rootstocks, trees grafted on 'M.9' and 'G.213' had similar tree high over the evaluated seasons (Table 1). The highest initial canopy volume was observed in Tall Spindle trained trees and grafted on 'G.213'; however, in the second evaluated season there were no statistical differences, except for Tall Spindle trees grafted on 'M.9', which obtained lower canopy volumes. In the last evaluated season, no differences were observed due to rootstocks, but

Table 4 - Red color intensity on fruits of 'Maxi Gala' and 'Fuji Suprema' apple trees grafted on 'M.9' and 'G.213' rootstocks trained at Tall Spindle and Bi-Axis systems in Southern Brazil.

Season	Training System/Rootstock	Red color intensity (°Hue) M.9	G.213	M.9	G.213
		---Maxi Gala---		---Fuji Suprema---	
2016/17	Tall Spindle	44.0 a^{*}	48.7 b	-	-
	Bi-axis	54.1 b^{*}	38.4 a	-	-
2017/18	Tall Spindle	43.6 b^{*}	37.4 a	31.6 a^{*}	35.3 b
	Bi-axis	38.2 a^{*}	41.4 b	31.3 a^{ns}	30.3 a
2018/19	Tall Spindle	39.9 a^{*}	39.1 b	33.5 b^{*}	36.3 b
	Bi-axis	41.9 b^{*}	34.9 a	30.9 a^{*}	34.9 a

Note: * represents significant and ^{ns} not significant according to the Tukey's test ($P \leq 0.05$) for comparison between rootstocks in the line. Means within a column followed by the same letter are not significantly different according to the Tukey's test ($P \leq 0.05$) for comparison between training systems.

between training systems the Bi-Axis induced higher canopy volume (Table 2). TCSA was higher in Tall Spindle trained trees grafted on 'G.213' in the first evaluated season. In the second, TCSA was similar for both training systems and rootstocks except for Tall Spindle trained trees grafted on 'M.9' which had lower TCSA. In the last season, no differences in TCSA were reported (Table 1). The largest number of lateral branches was observed in Bi-Axis trained trees and grafted on 'G.213' in all years of study (Table 1).

The fruit production showed variable behavior among seasons. In 2016/17 season, the highest yields were reported in Tall Spindle trained trees grafted on 'G.213'. The following season, the largest productions were reported on Bi-Axis trained trees grafted on 'G.213'. In the last evaluated season, differences were found only for Tall Spindle trained trees grafted on 'M.9' where they had the lowest fruit yield (Table 2). Regarding estimated yield, in the first two seasons, Tall Spindle-trained trees had the highest values, as well as 'G.213' grafted trees. In the last evaluated season, there was no difference between the training systems on this variable when grafted on 'M.9', but there was higher estimated yield in Tall Spindle-trained trees than Bi-Axis when grafted on 'G.213'. Still, trees trained in Tall Spindle had higher estimated yield when grafted on 'G.213' than grafted on 'M.9'; however, when trained in Bi-Axis, there was no differences between rootstocks (Table 2).

In the first evaluated season, the highest yield efficiencies were obtained on trees trained in Tall Spindle and on trees grafted on 'G.213'. In the following season, when the trees were grafted in 'G.213', they presented higher yield efficiency than those grafted in 'M.9' when trained in Bi-Axis, this training system also obtained higher yield efficiency than Tall Spindle trees when grafted on 'G.213'. In 2018/19 season, trees grafted on 'M.9' had greater yield efficiency than those trained in Bi-Axis, whereas for trees trained in Tall Spindle, greater yield efficiency was obtained on trees grafted on 'G.213' (Table 2).

No differences in fruit weight were observed except for the first evaluated season. Trees grafted on 'G.213' produced fruits with higher weight than trees grafted on 'M.9', as well as Tall Spindle trained trees produced fruits with higher weight than Bi-Axis trained trees. The same trend was observed in fruit diameter, it only differed in the first season, where larger diameter fruits were harvested from Tall Spindle trained trees when compared to fruits from Bi-Axis trained trees (Table 3). No differences in flesh firmness were observed between training systems

or between rootstocks, except for the last season of evaluation when the firmest fruits were obtained from trees trained in the Bi-Axis grafted on 'G.213'. For soluble solids content, no differences were observed between training systems and rootstocks for two evaluation seasons, except only in the first evaluated season, when the highest contents were reported in fruits from the trees grafted on 'G.213' (Table 3).

In the 2017/18 season, fruits from Tall Spindle trained trees grafted on 'G.213' showed lower red color intensity than fruits from 'M.9' grafted trees in this same training system. Also, higher intensity of red color was obtained on fruits of Bi-Axis trained trees than fruits of trees trained in Tall Spindle when grafted on 'G.213'. In the last season evaluated, the fruits with higher intensity of red color were obtained from the trees trained in Bi-Axis and the grafted trees on 'M.9' (Table 4).

DISCUSSION

Vegetative growth

The height, canopy volume and trunk cross-sectional area are important variables in determining the vigor of trees in an orchard. The Bi-Axis trained trees presented lower height, but higher values for canopy volume and trunk cross-sectional area, characterizing larger vigor than the trees trained in Tall Spindle. DORIGONI et al. (2011) evaluating the Fuji cultivar, observed very similar height growth between the Bi-Axis and Slender Spindle training systems, in contrast, also reported a larger trunk cross-sectional area in trees trained in Bi-Axis.

The Bi-Axis training system features the canopy vigor division into two main branches (MUSACCHI, 2008), so there is a larger trunk cross-sectional area and lower height, which has higher energy expenditure for training the two leaders as opposed to Tall Spindle trained trees that have only one main leader. Allied to this, the replanting condition in which the orchard is subjected may have influenced the growth, because apple trees subjected to the replanting conditions promote, among other factors, reduction of vegetative growth (HENFREY et al., 2015), causing lower tree height. The higher canopy volume of Bi-Axis trained trees can also be explained by the development of two leaders, as the assessment was done by tree and not individually by leaders. This may have occurred in greater intensity in this study because the trees trained in Bi-Axis have twice the spacing between trees; although, there are the same number of stems per area, there is less root competition among Bi-Axis trained trees.

Among rootstocks, the highest initial vigor of the trees was obtained on 'G.213', verified by the highest values of TCSA and canopy volume. Although, both are classified as dwarf rootstocks with similar growth pattern, 'M.9' grafted trees had lower vegetative development compared to 'G.213' under replanting condition, as the proven performance of the Geneva® series genotypes under these conditions, as well as the susceptibility of Malling series genotypes, which fit the rootstock 'M.9' (KVIKLYS et al., 2016). These results corroborated with AUVIL et al. (2011), who evaluated different areas under replanting conditions with fumigation treatments, the authors found that trees grafted on the Geneva® rootstocks showed greater development in places with and without fumigation treatment compared to other rootstocks.

The largest number of lateral branches was obtained in trees trained in Bi-Axis, probably due to the break in apical dominance in two leaders, which promoted reduction in height, but gives greater lateral bud sprouting. Our results corroborated those described by DORIGONI et al. (2011), in which trees trained in Bi-Axis determined a significantly different growth habit, having larger lateral branching compared to a single leader system.

The higher number of lateral branches obtained from trees grafted on 'G.213' agrees with other studies, which have observed that many Geneva® series rootstocks induce better bud sprouting than 'M.9' rootstock, culminating the formation of trees with more lateral branches (FAZIO et al., 2015). This may be possibly explained by the higher endogenous concentration of cytokines in 'G.213', altering the hormonal balance of the scion, favoring the development of lateral buds, as verified by LORDAN et al. (2017) in which the highest uniformity of shoots was obtained in trees grafted on rootstocks that gave the highest concentrations of trans-zeatin, which is the main cytokine present in plant xylem.

Yield components and fruit quality

Estimated yield was higher in Tall Spindle trained apple trees in most cases, never lower than Bi-Axis trained trees. However, it is important to point out that in many cases the individual yield per tree and the yield efficiency was the same for both systems, where the planting density was fundamental to differentiate the systems regarding to the estimated yield. Therefore, a solution to improve productivity would be to increase the tree density of Bi-Axis trained orchard as they have similar yield efficiency to Tall Spindle-trained trees. This can be seen in a study conducted by MUSACCHI (2008) on pear trees, where the author compares Slender Spindle and Bi-Axis trained trees at the same planting density (2857 trees ha^{-1}) and obtain the estimated yield and production per tree identical for both training systems.

The higher fruit production, yield and yield efficiency obtained in trees grafted on 'G.213' compared to those grafted on 'M.9', agree with the results observed by DENARDI et al. (2015) evaluating 'Gala' and 'Fuji' on both rootstocks in an area never cultivated with apple trees in the past, as well as MACEDO et al. (2021), which reported that 'G.213' provides higher yields and lowest biennial bearing rate in 'Maxi Gala' apples on replanting soil compared to those grafted on 'M.9'.

One of the reasons for the higher fruit yield on trees grafted on 'G.213' may be because the Geneva® series rootstocks induce a larger opening angle to the lateral branches on the canopy cultivars (FAZIO et al., 2015), which is related to greater formation of flower buds (ZHANG et al., 2015), which may result in higher yields. In addition, apple trees grown under replanting conditions promote yield reduction (MAZZOLA & MANICI, 2012), this may have aided the lower yield performance of the apple trees grafted on 'M.9', as their vegetative development was compromised, supporting smaller productions.

Although, observed in only one of the evaluation seasons, the lowest fruit weight obtained from trees trained in Bi-Axis was also reported by D'ABROSCA et al. (2017) evaluating nine different training systems. Nevertheless, in the other two seasons evaluated there were no differences between training systems and rootstocks, corroborating with PASA et al. (2016) and REIG et al. (2019) results, in which they did not find differences in fruit weight as the effect of different training systems on Imperial Gala, Fuji Mishima, Gala, Fuji and Honeycrisp apple cultivars.

The difference in fruit weight in only one of the evaluated seasons was probably not due to the difference in fruit number. REIG et al. (2019) described differences in fruit weight of apple trees grafted on different rootstocks, which had no influence on the number of fruits per tree or yield efficiency, as probably occurred in this study in trees trained in Tall Spindle and grafted on 'G.213', in which the production difference of 3.7 and 5.0 kg tree^{-1} or yield of 13 and 17 t ha^{-1} higher than the second most productive treatment in Maxi-Gala and Fuji Suprema cultivars, respectively. It cannot be explained just by the difference in weight, but by the higher number of fruits. The higher values obtained in the apple trees grafted on 'G.213' may be due to

the higher endogenous concentration of cytokines in this rootstock, which may increase the cell division of the fruit, promoting growth and weight increment even with higher yield. No differences in fruit diameter were observed between treatments in at least two evaluated seasons, corroborating with other studies that also reported no differences evaluating several training systems (SANDER et al., 2019) and rootstocks (LORDAN et al., 2018; MACEDO et al., 2021).

The intensity of the red color on apples and the synthesis of anthocyanins are regulated by internal and environmental factors, and the intensity of the light received by the fruit peel plays a key role in color development (GONZÁLEZ-TALICE et al., 2013). Therefore, the higher intensity of red in fruits from Bi-Axis trained trees can be explained by the better light distribution in the canopy due to the division into two main stems, especially for more vigorous cultivars such as 'Fuji' when compared to the 'Gala'.

Training systems influence fruit quality characteristics due to changes in the microclimate inside the canopy, which may result in greater peel coloration in better light interceptions training systems (GULLO et al., 2014). This result corroborated those reported by DORIGONI et al. (2011), who reported a higher coloration of fruits from Bi-Axis trained trees compared to fruits from 'Slender Spindle' trained trees, mainly three to four years after the orchard establishment. The differences in quality between the two systems became evident as the trees in 'Slender Spindle' developed large and shaded layers of branches that produced poor quality fruit at the bottom.

The higher fruit coloration obtained from the Tall Spindle trained trees on some of the few occasions may have occurred due to non-shading inside the canopy as they did not reach their maximum vegetative development. In addition, the removal of 2 to 3 whole branches each year enables better light distribution inside the canopy. The higher fruit coloration obtained from 'M.9' grafted trees may have occurred due to better light distribution, since there was less vegetative development and less lateral branch formation on this rootstock, highlighting the condition that the area of the orchard had already been cultivated with apple trees previously.

The absence of differences in flesh firmness and soluble solids in two of the evaluated seasons supports the findings of SANDER et al. (2019), who found no difference in either firmness or soluble solids by evaluating different apple tree training systems, as well as MACEDO et al. (2019 and 2021) evaluating

different rootstocks in southern Brazil and REIG et al. (2019) evaluating different combinations of apple cultivar, training systems and rootstocks under New York, United States climatic conditions.

DALLABETTA et al. (2017) evaluating the effect of light intensity on the Slender Spindle and Bi-Axis training systems, did not verify differences in flesh firmness. However, sweeter fruits were observed when they were picked in the most apical part in comparison to the basal part of the tree, but with no differences when positioned at the internal and external part at the same level horizontally in the canopy. The lower concentration of soluble solids in 'Maxi-Gala' apple Tall Spindle-trained trees during the last evaluation season may have been due to the lower exposure of fruits to light due to the higher shade, which can be seen by the higher tree height in this training system.

CONCLUSION

'Maxi Gala' apple trees Bi-Axis trained have higher vigor than Tall Spindle trained ones, as well as when grafted on the 'G.213' rootstock in both cultivars considering the replanting condition and the same number of stems per area.

The use of 'G.213' as rootstock for 'Maxi Gala' and 'Fuji Suprema' apple trees provides higher lateral branching and higher yields than 'M.9' under replanting conditions.

Tall Spindle-trained 'Maxi Gala' and 'Fuji Suprema' apple trees are more productive in the early years than when trained in Bi-Axis.

Higher intensity of red color occurs in Bi-Axis trained cultivars as well as 'Maxi Gala' grafted on 'G.213' rootstock. Others fruit quality parameters are not affected by the tested training systems.

DECLARATION OF CONFLICT OF INTEREST

The authors declared no conflicts of interest.

AUTHORS' CONTRIBUITIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically review the manuscript and approved the final version.

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